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Some Characteristics of Air Distribution at Application of Linear Crevice Diffuser

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Abstract

The organization of air distribution is one of the key aspects of creating a comfortable and healthy indoor climate. The effectiveness of this process affects not only temperature and humidity, but also overall air quality, which directly impacts people's well-being. To ensure optimal air distribution, a variety of ventilation devices are used, including grilles and diffusers, which differ in design and technical characteristics. Recently, louvered linear diffusers have gained considerable popularity, combining high functionality with modern design. These devices are in line with current architectural and design trends, where special attention is paid to aesthetics, integration into the interior and small details. With an innovative design with multiple parallel air outlets, louvered linear diffusers create unique airflows that actively interact with each other, contributing to turbulence and ensuring even air distribution in the room. This approach not only increases the efficiency of ventilation systems, but also creates comfortable conditions for staying, minimizing drafts and temperature fluctuations.

Keywords: linear diffuser; air distribution; flat jet; microclimate; air flow turbulence; thermal comfort.

1. Introduction

To ensure a comfortable stay of people in the room, create safe working and rest conditions, it is necessary to provide optimal microclimate parameters. These parameters of the microclimate, thermal comfort, depend on temperature, humidity, air velocity [1] and are mainly ensured by ventilation systems. In order for ventilation systems to correctly fulfill the task of ensuring thermal comfort, they must be designed properly. Proper design of the ventilation system requires accurate data on the operation of the diffusers.

2. Analysis of the recent publications and research works on the problem

The parameters of diffusers are the object of many studies [2], [3], [4], [5] which were carried out experimentally and using numerical simulations. However, such studies mainly concern vortex diffusers. Linear diffusers are a separate type of ceiling diffusers [6]. There are several studies of linear slotted diffusers [7], [8] with different aspect ratios, in which the parameters of the operation of ceiling diffusers and isothermal conditions were studied. Based on the results of these studies, a calculation technique was described that makes it possible to calculate the attenuation of the air jet velocity of a linear diffuser in two dimensions. When conducting research [9], the effect of the aspect ratio of a linear slotted diffuser on the appearance of drafts in a small office room and a large office space was studied.

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Also, studies [10] were carried out on the flow characteristics of a linear slotted diffuser and the possibility of their effective operation even in operating rooms [11] by the CFD simulation method.

The various air diffusers available on the market and offered by different manufacturers often have significant differences in design, despite the external similarities. Due to different ways of representing performance characteristics and differences in measurement methods, the selection and comparison of diffusers is not an easy task. Due to the insufficient level of knowledge about the operation of linear diffusers, there is a need for further study of this type of diffuser. In this article, we present some characteristics of the operation of diffusers.

3. Formulation of the goal of the paper

The article aims to analyze the effectiveness of using linear slotted diffusers in ventilation systems, to determine their optimal operating parameters, to assess the impact on the uniformity of air distribution in rooms, as well as to investigate their aerodynamic characteristics.

4. Presentation of research results

Like compact jets, flat jets have a similar structure. It is possible to delineate the core of the jet clearly, the pole of the jet and the boundaries of the jet, formed by the lines that pass through the pole of the jet and the boundaries of the linear louver diffuser.

During the experimental study of individual plane jets and their interaction, it can be noted that in the main area, the development of the jet is characterized by a gradual uniform drop in axial velocity v_x, and excess temperature, which is the difference in air temperature in the jet and in the room t_{in}: $\Delta t_x = t_x - t_{in}$. The question arises: how does their combination in a linear slotted diffuser affect the characteristics of flat jets?

It can be assumed that in the presence of parallel air outlets in the louvered linear diffuser, the interaction of flat jets occurs at the outlet of the diffuser, which causes significant turbulence of the total air flow and a sharper attenuation of the jet velocity as a result.

The axial velocity in isothermal jets v_x, m/s, is determined by the formula [12]:

$$v_x = DC/x, \tag{1}$$

where x is the current longitudinal coordinate, m; $DC$is dynamic characteristic, m^2/s.

The dynamic characteristic, in turn, is defined as [12]:

$$DC = \frac{0.66}{\mathrm{tg}\alpha}\sqrt{\frac{T_{in}}{T_n}} \cdot \sqrt[4]{\xi} \cdot V_n \cdot \sqrt{F_n}, \tag{2}$$

where α is the angle of opening of the jet ($\alpha = 12°25'$; $\mathrm{tg}\alpha = 0.22$); ξ is local resistance coefficient of the diffuser slit under study (ξ =1); T_{in}, T_n are room temperature and diffuser slot outlet temperature, respectively, K; $V_n$is initial velocity at the diffuser slot outlet in a linear slotted diffuser, m/s; F_n is area of the air outlet nozzle in the linear diffuser, m^2.

For simplification and convenience of calculations, the velocity attenuation coefficient *VD* is used [12]:

$$VD = \frac{0.66}{\mathrm{tg}\alpha}\sqrt{\frac{T_{in}}{T_n}} \cdot \sqrt[4]{\xi}. \tag{3}$$

Axial velocity is now calculated by the following formula [12]:

$$v_x = VD \cdot V_n \cdot \frac{\sqrt{F_n}}{x}. \tag{4}$$

In horizontally released weakly non-isothermal jets, the excess temperature is determined by the formula [12]:

$$\Delta t_x = \frac{TC}{x}, \quad (5)$$

where TC is thermal characteristic, °C·m, determined by the following formula [12]:

$$TC = \frac{0.54}{\text{tg}\alpha} \sqrt{\frac{T_{in}}{T_n}} \cdot \frac{1}{\sqrt[4]{\xi}} \cdot \Delta t_n \cdot \sqrt{F_n}, \quad (6)$$

where Δt_n is initial excess temperature ($\Delta t_n = t_n - t_{in}$), °C.

For the convenience of calculations, a temperature attenuation coefficient *TD* is introduced [12]:

$$TD = \frac{0.54}{\text{tg}\alpha} \sqrt{\frac{T_{in}}{T_n}} \cdot \frac{1}{\sqrt[4]{\xi}}. \quad (7)$$

Then the formula for determining the axial excess temperature Δt_x will be as follows [12]:

$$\Delta t_x = TD \cdot \Delta t_n \cdot \frac{\sqrt{F_n}}{x}. \quad (8)$$

Accordingly, in any section "x" at a distance "y" from the axis, the excess temperature $\Delta t_y = t_y - t_{in}$ is determined by the Taylor's formula [12]:

$$\Delta t_y = \Delta t_x \cdot \exp\left(-0.7\sigma_T \bar{y}^2\right) \quad (9)$$

where σ_T is Prandtl's turbulent number (σ_T = 0.65 ÷ 0.7 for compact jets); $\bar{y} = y/(cx)$; y is current transverse coordinate, m; c is an experimental constant (c = 0.28).

However, for simplification, it is advisable to use the relative values of excess temperatures, axial $\Delta\bar{t}_x = \Delta t_x/\Delta t_{in}$ and in any section $\Delta\bar{t}_y = \Delta t_y/\Delta t_{in}$.

The study of the parameters of the jet formed during the operation of a linear louver diffuser took place at a laboratory experimental facility. The installation diagram is shown in Fig.1.

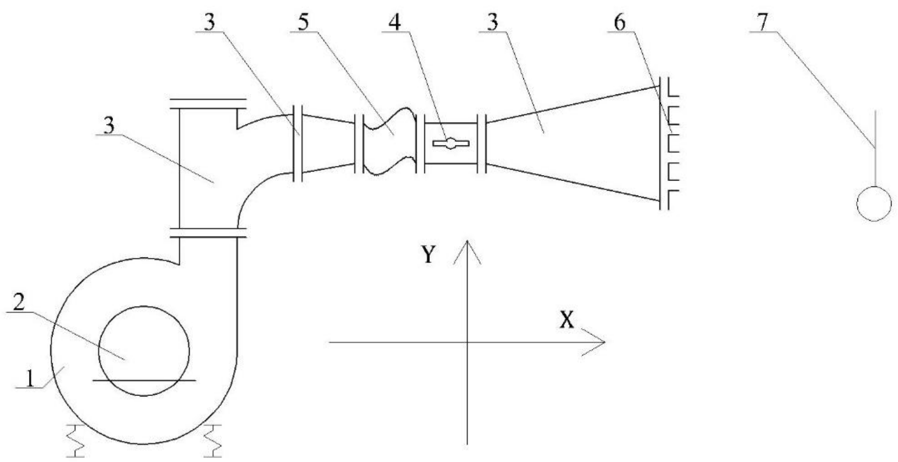

Fig.1. Scheme of the experimental setup: 1 – centrifugal fan; 2 – electric motor; 3 – air duct; 4 – control valve; 5 – flexible insert; 6 – linear slot diffuser; 7 – testo-405 thermal electrical anemometer.

The study was carried out for a linear slotted diffuser with four outlet slots. The diffuser under study, the experimental setup, and the research process, including the location of the sensors, are shown in Fig.2. The installation consists of a centrifugal fan on a vibration-insulated base for a stable air supply, a control choke to set the required flow, an air duct system that ensures even air distribution in front of the built-in linear diffuser, and an air velocity and temperature measurement system.

a)

b)

c)

d)

Fig.2. Experimental setup photographs: *a)* linear diffuser; *b)* general view of installation; *c)* visualization of jet; *d)* jet boundary.

As a result of processing the array of received data, the following dependence was confirmed and obtained:

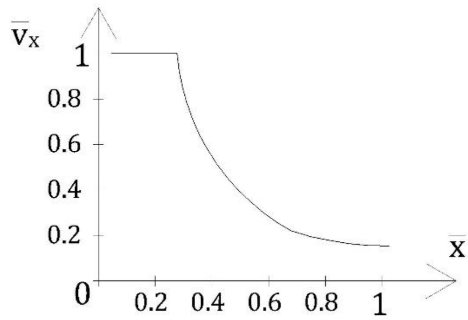

Fig.3. Dependence of relative axial velocity on longitudinal coordinate $\overline{v}_x = f(\bar{x})$ for linear slot diffuser.

From the dependence shown in Fig.3, it can be concluded that the air flow is intensely turbulent, the velocity attenuation in the jet occurs actively. The value of the velocity attenuation coefficient for a linear slot diffuser is equal to *VD* = 1.0, which is smaller compared to the same coefficient for a rectangular flat slot, for which *VD* = 2.5.

5. Conclusion

1) The conducted studies and obtained dependences of the velocity drop in an isothermal flat jet make it possible to supplement the existing methods of calculating linear slot diffusers and using them in premises for various purposes.

2) The hypothesis put forward on the interaction of several jets in a linear slot diffuser has been confirmed. The interaction of several jets at the outlet of the linear diffuser results in a sharper decrease in the axial velocity of the supply jet by 10 - 20% depending on the current coordinate in comparison with conventional air distributors.

3) The velocity attenuation coefficient for a linear slot diffuser *VD* = 1.0 gives us a possibility to use them in ventilation systems for premises with special requirements. Such characteristics allow organizing ventilation in premises without the occurrence of drafts.

4) A specific velocity profile is observed in the cross section of the jet due to the design features.

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Деякі характеристики повітророзподілу при застосуванні лінійного щілинного дифузора

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Анотація

Організація повітророзподілу є одним із ключових аспектів створення комфортного та здорового мікроклімату в приміщеннях. Від ефективності цього процесу залежить не лише температура й вологість, а й загальна якість повітря, що безпосередньо впливає на самопочуття людей. Для забезпечення оптимального розподілу повітря використовуються різноманітні вентиляційні пристрої, зокрема решітки та дифузори, які відрізняються конструкцією й технічними характеристиками. Останнім часом значної популярності набули жалюзійні лінійні дифузори, що поєднують високу функціональність із сучасним дизайном. Ці пристрої відповідають актуальним архітектурним і дизайнерським тенденціям, де особлива увага приділяється естетиці, інтеграції в інтер'єр та дрібним деталям. Завдяки інноваційній конструкції з кількома паралельними повітровипускними щілинами, жалюзійні лінійні дифузори створюють унікальні повітряні потоки, які активно взаємодіють між собою, сприяючи турбулізації та забезпечуючи рівномірний розподіл повітря в приміщенні. Такий підхід не лише підвищує ефективність вентиляційних систем, а й створює комфортні умови для перебування, мінімізуючи протяги та температурні перепади.

Ключові слова: лінійний дифузор; подача повітря; плоский струмінь; мікроклімат; турбулізація повітряного потоку; тепловий комфорт.